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October 29, 2021

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
600 East Boulevard Avenue, Department 405
State Capitol, 14th Floor
Bismarck, ND 58505-0840

Dear Ms. Fine:

Subject: Quarterly Progress Report for the Period of July 1 – September 30, 2021, "Produced Water Management Through Geologic Homogenization, Conditioning, and Reuse" Contract No. G-051-010

Attached please find the Energy & Environmental Research Center (EERC) Quarterly Progress Report for the subject project. If you have any questions, please contact me by phone at (701) 777-5421 or by e-mail at kglazewski@undeerc.org.

Sincerely,

DocuSigned by:
DFF46D8431F8412...
Kyle A. Glazewski
Senior Analyst

KAG/kal

Attachment

c/att: Michael Holmes, Lignite Energy Council
Brent Brannan, North Dakota Industrial Commission (NDIC) Department of Mineral Resources, Oil and Gas Division

c: Paul Arnason, EERC

PRODUCED WATER MANAGEMENT THROUGH GEOLOGIC HOMOGENIZATION, CONDITIONING, AND REUSE

Quarterly Technical Progress Report

(for the period July 1 – September 30, 2021)

Prepared for:

Karlene Fine

North Dakota Industrial Commission
600 East Boulevard Avenue, Department 405
State Capitol, 14th Floor
Bismarck, ND 58505-0840

Contract No. G-051-010

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PRODUCED WATER MANAGEMENT THROUGH GEOLOGIC HOMOGENIZATION, CONDITIONING, AND REUSE

EXECUTIVE SUMMARY

The Energy & Environmental Research Center (EERC), in partnership with Nuverra Environmental Solutions (Nuverra) and the North Dakota Industrial Commission Oil and Gas Research Program (OGRP), is assessing the techno-economic viability of using the Inyan Kara Formation as a geologic solution for produced water treatment and recycling. This Stage I effort is investigating this new approach, herein referred to as geologic homogenization, conditioning, and reuse (GHCR), to managing produced water while simultaneously addressing oil and gas industry challenges related to the management of increasing volumes of produced water and resulting pressurization of geologic formation use for saltwater disposal. GHCR takes advantage of natural processes occurring in the subsurface (such as dilution, mixing, and filtering) to improve produced water quality prior to extraction for subsequent reuse. The GHCR concept represents a nontraditional and potentially transformational approach to produced water management. The benefits of the concept include using existing infrastructure and industry practices, enabling large-volume subsurface storage of produced water, displacing freshwater demand within the industry, and reducing the magnitude and rate of pressurization of the target formation. This progress report represents an update of the Produced Water Management Through Geologic Homogenization, Conditioning, and Reuse activities from July 1 through September 30, 2021.

A second laboratory-scale column study using crushed Inyan Kara outcrop material with injection of high-salinity Bakken brine was completed. The study was conducted to evaluate formation chemistry impacts in comparison to the control experiment completed in 2021 Quarter 2 that evaluated the physical filtering of the Bakken brine. A third laboratory-scale column study using Inyan Kara core was initiated to provide flow-through analysis of true Inyan Kara core (rock). These additional column studies have each enhanced the project team's understanding of the expected processes and reactions occurring in the Inyan Kara Formation when exposed to produced water. Two additional numerical models at laboratory scale are being built to analyze the interaction of the fluids and the Inyan Kara Formation outcrop and core. Several scenarios were evaluated in the field-scale simulation, including the number of production wells, distance between injector and producer wells, and the production/injection rate. Feedback from other project activities was incorporated into the techno-economic analysis (TEA), and a summary of the TEA framework and preliminary results was prepared. Several TEA assumptions regarding the recycling potential of GHCR produced water have been based on insights from project activities.

PRODUCED WATER MANAGEMENT THROUGH GEOLOGIC HOMOGENIZATION, CONDITIONING, AND REUSE

ACCOMPLISHMENTS

Major Goals of the Project

The Energy & Environmental Research Center (EERC) was awarded a contract by the North Dakota Industrial Commission (NDIC) Oil and Gas Research Program (OGRP) (NDIC No. G-051-101) to conduct a study on the recycling of water used in oil and gas operations, also known as produced water, from oil- and gas-producing regions of North Dakota as directed by Section 19 of North Dakota House Bill 1014. The EERC, in partnership with the NDIC OGRP, the U.S. Department of Energy (DOE), and Nuverra Environmental Solutions (Nuverra), will assess the techno-economic viability of using the Inyan Kara Formation as a geologic solution for produced water treatment and recycling, with the added benefit of providing a potential solution to pressurization of the Inyan Kara Formation in North Dakota. This update is for July 1 through September 30, 2021.

This Stage I effort will provide data on current methods for produced water treatment and recycling and assess the commercial viability of geologic homogenization, conditioning, and reuse (GHCR) for produced water management. In addition to developing and compiling data regarding produced water management methods, the project investigates a new approach to managing produced water while simultaneously addressing oil and gas industry challenges related to the management of increasing volumes of produced water and pressure increases in the Inyan Kara Formation. If successful, the GHCR concept offers an attractive technological and economic solution for managing produced water through 1) incorporating existing industry practices and infrastructure to homogenize and condition produced waters for subsequent treatment and/or reuse; 2) enabling large-volume storage and a virtually limitless supply of consistent-quality produced water for subsequent beneficial reuse, displacing freshwater demand and thereby providing assurance of future water supply; and 3) reducing the net volume of saltwater disposal (SWD), thus reducing the magnitude and rate of pressurization of the target disposal formation, extending the life of SWD wells, and reducing oil and gas development costs associated with Inyan Kara pressurization.

The project goal is to assess the techno-economic viability of using the Inyan Kara Formation as a geologic solution for produced water treatment and recycling. Specific research objectives related to this goal are as follows:

- Evaluate produced water management methods, trends, and costs; capacity of water supply and disposal facilities; and economic, regulatory, and technological considerations for water recycling and reuse applications relevant to Bakken produced water management.

- Aim to replicate the interaction between Bakken produced water and the Inyan Kara Formation through laboratory experiments.

- Simulate the performance of the GHCR concept using geologic and geochemical models.

- Assess the techno-economic viability of the GHCR concept, including the relevant economic, regulatory, scientific, technological, and feasibility considerations affecting potential commercial adoption of GHCR.

Accomplishments under These Goals (for the reporting period)

Technical project meetings were held biweekly to discuss progress of all activities.

Activity 1.0 – Produced Water Assessment

All activities under Activity 1.0 were completed September 30, 2020.

Activity 2.0 – Field and Laboratory Validation

A second column study was completed this quarter using Inyan Kara outcrop material to compare to the previous study using quartz sand. The objective is to evaluate the interaction between Bakken produced water and the Inyan Kara Formation. The outcrop material, part of the Fall River member of the Inyan Kara Formation, was collected from a location in South Dakota near Rapid City. As with the previous study, synthetic Inyan Kara brine had been used to saturate the Inyan Kara outcrop material, and a high-salinity Bakken brine was used for injection into the laboratory column. The total dissolved solids (TDS) of the brine sample were measured at 340,000 mg/L. Injection of the Bakken brine into the column began on June 23, 2021. Sample collection at the exit of the column continued throughout the study, and samples were monitored for conductivity periodically. At the end of the column study on September 15, 2021, the conductivity reached high plateau value and remained steady at approximately 255 mS/cm. Eight samples were chosen for full chemical analysis, which represented the beginning, midpoint, and end of the study period. Initial results show that most parameters were tracking with the increase in TDS and conductivity, similar to what was observed in the sand column study. Sample analysis is ongoing to evaluate all parameters.

Core samples from the Inyan Kara Formation were placed in a second column within the laboratory system for flow-through testing to provide flow-through analysis of true Inyan Kara core (rock). Fourteen 3.0-cm-diameter, 8.9-cm-long core plugs sampled from well depths ranging from 5286 to 5322.7 ft were stacked to create a 1.24-meter-long composite column representative of the Inyan Kara Formation. The core was presaturated in the core holder with the same composition of synthetic Inyan Kara brine as used on the other column studies. After initial saturation, the same high-salinity Bakken brine used in the outcrop column study was used for injection. The injected brine for all studies was prefiltered to 200 μm to match the filtration level that filter socks use at injection sites. An injection flow rate of 0.007 mL/min was used. This flow rate represents the minimum flow rate that was reliably achievable. Injection was started on July 26, 2021. The sample collection rate is 10× slower than achieved in the silica and outcrop sand studies, resulting in a weekly produced fluid sampling instead of daily sampling. The testing for the core flow-through study was ongoing at the end of the reporting period. Initial exit sample results show that significantly more hydrocarbons are being produced from the core flow-through test than were observed in the silica and outcrop sand column studies. This has inhibited the reliable use of standard conductivity measurements to evaluate breakthrough injected brine. Alternative analysis is being performed. The current hypothesis is that the additional hydrocarbons are coming from the core which was preexposed to hydrocarbons during wastewater disposal.

Six additional samples of Bakken produced water were collected on September 29 and 30, 2021, from brine disposal complexes in different areas of the Williston basin. These samples will be analyzed for major and minor ions. The data will be used to enhance the assessment of Bakken produced water chemistry across the basin.

Activity 3.0 – GHCR Treatment Simulation

Two additional numerical models at laboratory scale, one for the second column study using Inyan Kara outcrop material, and another simulation model for the core plugs sampled from the Inyan Kara Formation, are currently being built using the compositional Computer Modelling Group (CMG) GEM simulator to analyze the interaction of the fluids and the Inyan Kara rock. The laboratory-scale model for the second column using outcrop material is currently being calibrated using the injection and production data from the Activity 2.0 study. TDS values determined for different water samples collected from the exit of the column at different dates are used for the numerical model calibration.

For the field simulation model, using field data from the Best Extraction and Storage Test (BEST) project site, different scenarios have been evaluated, including the number of production wells, distance between injector and producer wells, and the production/injection rate. The injection and production rates have been evaluated during the prediction for better control of the formation pressure and water salinity and to maximize the water production demanded for hydraulic fracking for the different total number of well scenarios evaluated. Preliminary simulation results have shown that the pressure formation can be reduced and restrained with proper injection/production rate control conditions and effectively maximize the water production. A decrease in salinity concentration has also been observed in the model for the BEST-E1 well when additional production wells are added within a distance no greater than 5 miles from the SWD1 and SWD2 injection disposal wells.

Activity 4.0 – Techno-Economic Assessment

This quarter, feedback from other project activities was incorporated into the techno-economic analysis (TEA), and a summary of the TEA framework and preliminary results was prepared. Several TEA assumptions regarding the recycling potential of GHCR produced water have been based on insights from Activities 3.0 and 4.0. For instance, the experiments of Activity 2.0 have generally demonstrated a beneficial conditioning of produced fluid after pumping it through formation column surrogates, and these results suggest minimal to no treatment will be needed for GHCR produced water reuse. Additionally, the modeling of Activity 3.0 suggests that large-scale flow through a modeled section of the Inyan Kara Formation can effectively homogenize the produced fluid over horizontal distances that fit within the boundaries of an individual Bakken drill spacing unit (DSU). The modeling also suggests that the total quantity of GHCR produced fluid can exceed the estimated hydraulic fracturing and maintenance water demand at an individual DSU.

A potential constraint highlighted by modeling that the TEA addresses is that of matching the rate of GHCR production to the high-flow, short-duration demand of hydraulic fracturing. Modeling showed the rate of GHCR production to be sensitive to the reservoir pressure, nearby injection activity, and the total number of GHCR production wells. In order to effectively evaluate the uncertainty that this issue presents, the TEA includes sensitivity studies of single and multiple GHCR well additions and a study that varied the ratio of GHCR wells to the number of oil wells these can support. These results clearly show the economic benefit of distributing the cost of GHCR development over multiple oil wells, but they also give indication of the potential costs if the number of supported oil wells must be reduced because of flow constraints at a given site.

Plan for the Next Reporting Period to Accomplish the Goals

All work under Activity 2.0 (Field and Laboratory Validation) and Activity 3.0 (GHCR Treatment Simulation) will be completed. Results will be compiled into the draft final report, which will be submitted by November 30, 2021, for review.

The laboratory column studies using core samples from the Inyan Kara Formation placed in a second column within the laboratory system for flow-through testing will be completed. Exit samples will be collected and analyzed periodically for conductivity to evaluate when breakthrough occurs. Based on conductivity trends, samples will be chosen and analyzed for additional parameters to provide input values for the modeling efforts. Samples of the outcrop material and core samples in the laboratory column study will be evaluated for microscopic mineral evaluations using scanning electron microscopy, x-ray diffraction, and x-ray fluorescence.

The last quarterly sampling of the BEST-E1 well is planned for early October 2021. Routine analysis will be conducted, and a compilation of all results over the project will be compiled for the draft final report.

The laboratory numerical simulation model study for the column study using Inyan Kara Formation core samples will be completed. Simulation results will be analyzed to understand the chemical reactions that may take place because of the interaction between the two different waters (the Bakken produced water and the native Inyan Kara water) with the Inyan Kara Formation rock that is being used. This will aid in the evaluation and prediction of the different aqueous and mineral reactions that may occur during the water injection/production process.

The field-scale model study will be completed. The simulation results from the injection/production scenarios will be analyzed to understand their effect on salinity concentration of the injected produced water, understand the reduction and control of pressure in the target formation, and maximize the water production capacity under these new operational conditions.

Plans for the TEA are to solicit and incorporate member feedback and finalize the TEA. This final analysis will be included in the draft final report.

CHANGES/PROBLEMS

Changes in Approach and Reasons for Change

In Activity 2.0, two additional laboratory column studies were evaluated to increase the overall understanding of the GHCR concept. The original scope called for a column study consisting of Inyan Kara outcrop material from South Dakota, which is still included in the project. The team evaluated an additional clean silica sand column test to better understand the reactions between Inyan Kara water with Bakken produced water independent from formation rock chemistries. A core sample from the BEST-E1 well was added to the project to provide analysis of true Inyan Kara core (rock) that is present at the BEST project location. The core sample column study was ongoing at the end of the reporting period. These additional column studies have each enhanced the project team's understanding of the expected processes and reactions occurring in the Inyan Kara Formation when exposed to Bakken produced water. These additional column studies have also led to two additional model/simulations under Activity 3.0 to aid in understanding the different chemical processes that are taking place. These modeling and simulation efforts were ongoing at the end of the reporting period since the Activity 2.0 studies were ongoing.

Actual or Anticipated Problems or Delays and Actions or Plans to Resolve Them

As outlined in the previous section, two additional laboratory column tests were added to Activity 2.0. While these have enhanced the learnings of the project, they have pushed the timeline back on completion of Activity 2.0. This has caused a slight delay to acquiring data for, and added work to, Activity 3.0. However, the benefits of the increased data and knowledge gained outweighs the delayed timeline. This is not expected to affect the overall project timeline nor final reporting, as extra time was built in to the original project timeline to account for possible delays in field (e.g., weather delays, operational delays) or laboratory efforts (e.g., supply delays or operational delays such as plugging in the columns or broken equipment).